MANAGEMENT STRATEGIES FOR URBAN STREAM REHABILITATION

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Abstract

Physical, hydrological, social, and biological conditions were evaluated at 45 stream sites in the Puget Lowland of western Washington, with watersheds ranging in area between 5 and 69 km^2 and having urban development as their dominant human activity. Using the benthic index of biotic integrity (B-IBI) as our biological indicator, we found a progressive decline in B-IBI with increasing watershed imperviousness but with large site-to-site differences at any given level of imperviousness in the contributing watershed. This variability is greatest at low to moderate levels of development; as development intensity increases, the range of biological conditions narrows. No threshold effects are apparent. Instream biological condition also varied directly with a new stream flow metric, showing significantly better correlations than with imperviousness. We also found a wide range of landscape conditions, some very degrading, in the backyards adjacent to these streams. These data do *not* suggest that the full range of hydrological and other ecological conditions can be replaced in a now-degraded urban channel; thus key management tasks are to identify those watersheds where low urbanization and associated high-quality stream conditions warrant protection, and to develop a new set of management goals for those watersheds whose surrounding development precludes complete ecosystem restoration but in which some recovery might be possible. There is no rational basis to support a common strategy in *all* watersheds, developed and undeveloped alike.

Introduction

For decades, watershed urbanization has been known to harm aquatic systems. Although the problem has been long articulated, solutions have proven elusive because of the complexity of the problem, the evolution of still-imperfect analytical tools, and socio-economic and political forces with different and often incompatible interests.

Recent Endangered Species Act (ESA) listings of Puget Sound chinook and bull trout, and the potential for more salmonid listings, have brought new scrutiny to all aspects of the Pacific Northwest's watershed protection and urbanization-mitigation efforts. Such increased attention is forcing a better articulation of the goals, the means, and the justification for mitigating the effects of urban development. It also has highlighted the failure of most stormwater mitigation efforts, not only in the Pacific Northwest but also across the country, where well-publicized successes are overshadowed by progressive degradation of once-healthy streams. This degradation has continued, despite sincere but ineffectual efforts via structural "Best Management Practices" (BMP's), particularly detention ponds, buffer regulations, and rural zoning.

Several factors make Puget Sound ideal for this study. Streams within our study region share relatively uniform soil, climate, and topography, allowing direct comparisons among streams. The region has a wide range of watershed development intensities and ages within a circumscribed area, including minimally developed areas that serve as reference sites. All study watersheds have (or once had) diverse natural biotas, including anadromous salmonids; some moderately developed watersheds still support regionally valuable biological resources that merit protection and enhancement. Individuals and citizen groups support protection of aquatic resources in general and salmon in particular, and these groups are the focus of a variety of local agency efforts to improve public education and stewardship. Finally, major expenditures in the region are expected over the next decade in the name of "stream enhancement." Improved knowledge should help direct these outlays to activities most likely to protect the region's aquatic life (including its iconic endangered salmonids), protect water quality, and thereby maintain cherished components of the region's quality of life.

Study Sites and Methods

For this study, we focused on 45 sites selected from 16 second and third-order streams in King, Snohomish, and Kitsap counties (Fig. 1) that share the following physical characteristics: (1) watershed area between 5 and 69 km^2; (2) local channel gradients between 0.4 and 3.2 percent; (3) soils, elevation, and climate typical of the central Puget Lowland; and (4) urban development as the dominant human activity (except in low-disturbance reference sites).

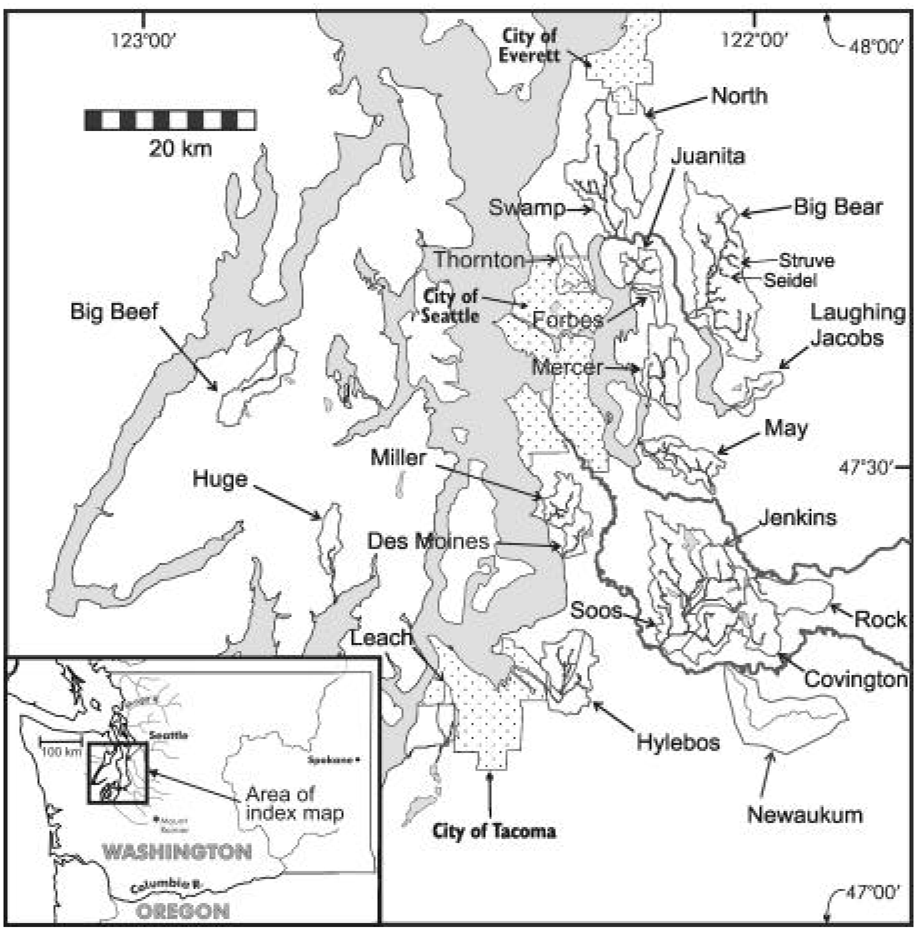

Figure 1: Map of Puget Lowland showing location of study streams and watersheds.

We explored the nature, and the causes, of change to aquatic-system health along a gradient of human activity. We used common measures of land cover (road density and total impervious area percentages) to characterize that "human activity." Benthic invertebrates were sampled at each site between 1997 and 1999 (Morley, 2000; Morley and Karr, 2002). Substrate data were collected at 19 of the sites, and hydrologic analyses were made at the 18 sites located in close proximity to gauging stations without intervening tributary input (Konrad, 2000). Hydrologic analyses for ten additional lowland streams of similar characteristics, but some with watershed areas up to 171 km^2, were also conducted. The social assessment had three parts—a survey of stream professionals, an in-depth evaluation of the landscape conditions in backyards adjacent to streams, and an evaluation of the values held by residents.

Although the hydrologic consequences of urban development are well documented at the scale of an individual storm (e.g., Hollis, 1975), consequences over longer periods are less well known. Because we expected the latter effects to be especially important to the biota of streams, we applied a hydrologic statistic to represent the annual distribution of storm and baseflow patterns: namely, the fraction of a year that the daily mean discharge exceeds the annual mean discharge (T_{Qmean}).

T_{Qmean} was calculated for each of the 18 streams by first determining the fraction of the year that the daily mean discharge (Q_{daily}) exceeded the annual mean discharge (Q_{mean}) for each year of record for each stream. T_{Qmean} was then calculated as the average annual fraction of a year that Q_{daily} exceeds Q_{mean}, which averages about 30 percent of the time across this range of Puget Lowland streams.

Results

Biological Condition at Multiple Land-Cover Scales

Relationships between land cover and biological conditions display several trends. As a group, our study sites display a progressive decline in B-IBI (Karr, 1998) with increasing urban development, although large site-to-site differences exist at any given level of imperviousness in the contributing watershed (Fig. 2). This variability is particularly evident at low to moderate levels of development, where almost any degree of biological condition may be associated with a given level of imperviousness (see also Karr and Chu, 2000). As development intensity increases, the range of biological conditions narrows until, in the most urban of our watersheds, conditions are uniformly poor.

Across all study sites, urban land cover (i.e. the combination of "intense," "grassy," and "forested" urban categories) correlated approximately equally well with B-IBI at each of three spatial scales: ***subbasin*** (i.e., the entire watershed area upstream of the sample point; $r = -0.73$, $p < 0.001$), ***riparian*** (a 200-m-wide buffer on each side of the stream extending the full length of the upstream drainage network; $r = -0.75$, $p < 0.001$), and ***local*** (a 200-m-wide buffer on each side of the stream extending 1 km upstream; $r = -0.71$, $p < 0.001$) (Morley and Karr, 2002). In our data set, riparian and subbasin land cover closely correlated with each other ($r = 0.98$, $p < 0.001$).

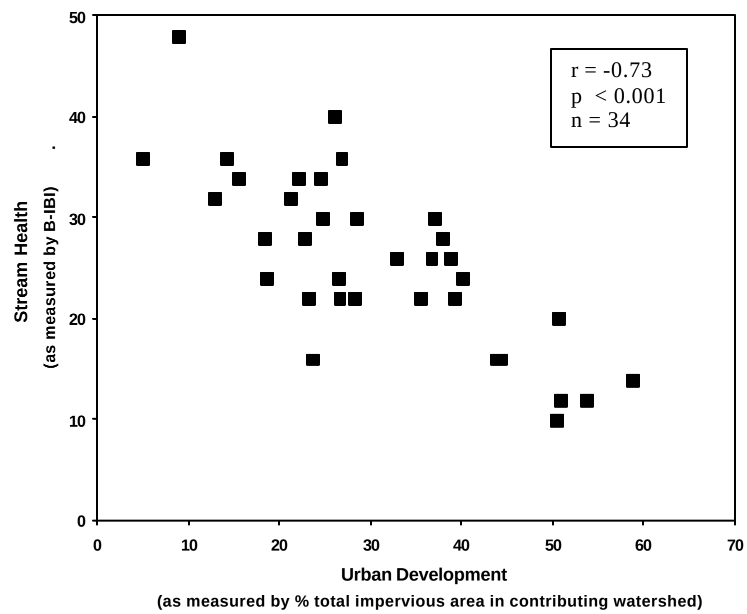

Figure 2: Relationship between watershed urbanization and stream health (i.e. biological condition) for our study streams as measured by total impervious area in the watershed upstream of benthic invertebrate sampling sites. Stream health is measured using the benthic index of biological integrity (B-IBI); samples collected 1997, 1998, and1999.

Hydrologic Changes

Hydrologic effects of urban development are evident, even amidst the variability generated by physiographic differences among the basins in the Puget Lowland. In urban streams (road density >6 km/km^2), the fraction of time that the mean discharge is exceeded (T_{Qmean}) generally is less than 30% (and all ≤ 32%), while in suburban streams (road density <6 km/km^2), T_{Qmean} is generally greater than 30% (and all but one ≥ 32%; Fig. 3). For WY 1989 to 1998, the mean value of T_{Qmean} for 11 urban streams was smaller (0.29) than for 12 suburban streams (0.34). The difference is statistically significant ($p < 0.01$ using Student's t-test of samples with equal variance). Independent of urban development, however, larger streams typically have more attenuated stream flow patterns than smaller streams and so higher values of T_{Qmean} (Konrad and Booth, 2002). Thus T_{Qmean} may only be a reliable indicator of urban development if stream basins are similar in drainage area and other physiographic factors.

The biological conditions of streams varied directly with this stream flow metric (Fig. 4), with significantly better correlations than for simple land-cover metrics (see Fig. 2). Variability in B-IBI is still significant, however, because flow regime is only one factor controlling biotic integrity; for any value of T_{Qmean}, the B-IBI range is about 10.

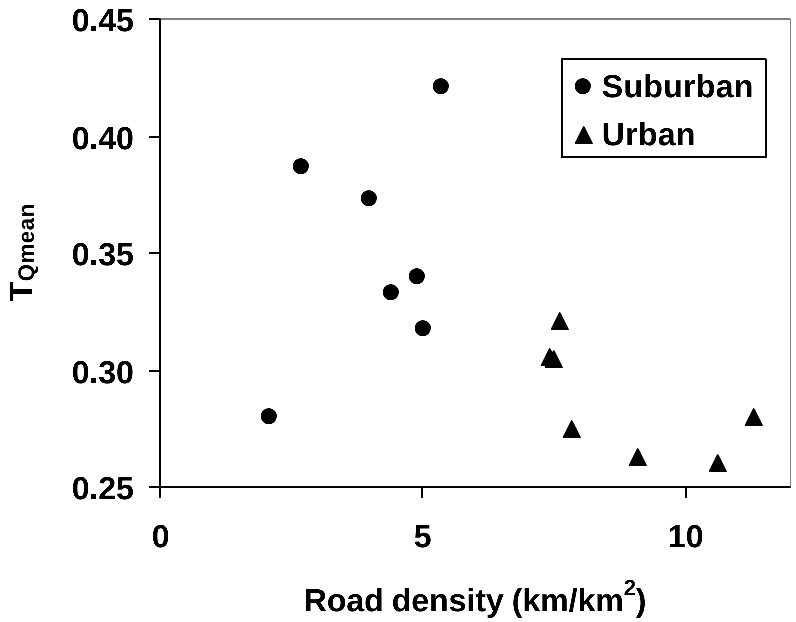

Figure 3: Fraction of year that mean discharge rate is exceeded (T_{Qmean}) as a function of watershed road density.

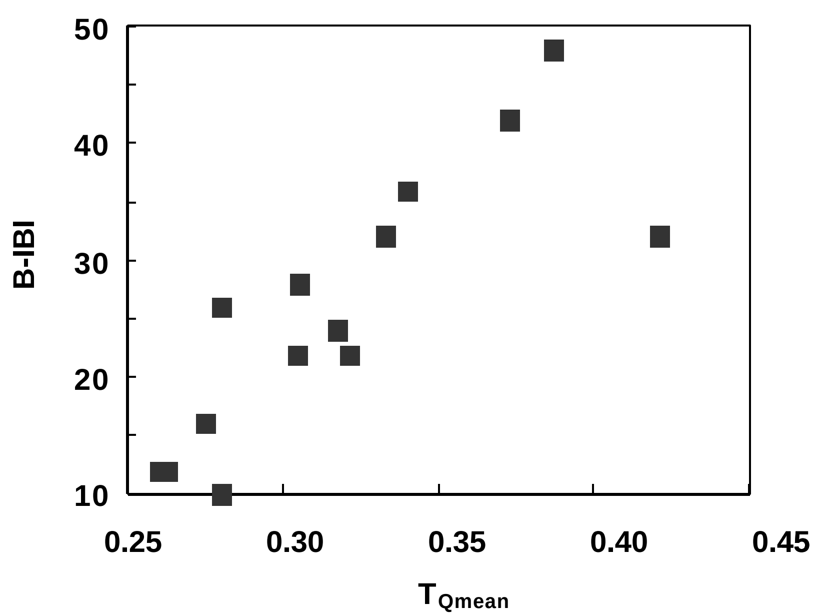

Figure 4: Benthic index of biological integrity (B-IBI) plotted against fraction of time that daily mean discharge rate exceeds annual mean discharge rate (T_{Qmean}) for Puget Lowland streams with biological and hydrologic data.

Social Assessment

The social assessment yielded a rich array of results. The most insightful was finding a wide variation in backyard conditions where streams were located. These subject properties ranged from those adjacent to streams, located in watersheds having a county-funded steward who provided extensive public education, to backyards in neighborhoods with little community awareness of the stream at all. In all locations the range of conditions varied from benign neglect to severe, "ecopathic" destruction of the landscape adjacent to the stream. Broad social measures do not explain these differences in behavior, but the influence of these actions on stream health (whether benign or damaging) was locally very significant.

Discussion

Correlations between watershed development and aquatic-system conditions have been investigated for over two decades. Klein (1979) published the first such study, where he reported a rapid decline in biotic diversity where watershed imperviousness much exceeded 10 percent. Steedman (1988) believed that his data showed the consequences of both urban land use and riparian condition on instream biological conditions. Later studies, mainly unpublished but covering a large number of methods and researchers, was compiled by Schueler (1994). Since that time, additional work on this subject has been made by a variety of Pacific Northwest researchers, including May (1996), Booth and Jackson (1997), Karr (1998), and Morley and Karr (2002)

These data have several overall implications:

- "Imperviousness," although an imperfect measure of human influence, is clearly associated with stream-system decline. A wide *range* of stream conditions, however, can be associated with any given level of imperviousness, particularly at lower levels of development.

- "Thresholds of effect," articulated in some of the earlier literature (e.g., Klein, 1979; Booth and Reinelt, 1993) exist largely as a function of measurement (im)precision, not an intrinsic characteristic of the system being measured. Crude evaluation tools require that large changes accrue before they can be detected, but lower levels of development may still have consequences that can be revealed by other, more sensitive methods. In particular, biological indicators (e.g., Figure 2) demonstrate a continuum of effects, not a threshold response, resulting from human disturbance (Karr and Chu, 2000).

- Although direct correlation of imperviousness with biological health is overly simplistic, imperviousness is a useful index of human activity in a watershed because it provides a gross measure of the watershed area appropriated by people, and thus it functions as a first-order indicator of human influence on selected processes supporting stream ecosystems. Many of the changes that degrade streams are progressively more likely to occur as human activity increases (Booth et al., 2002). The fraction of impervious area is not a suitable surrogate of stream health, however, because this metric neither captures nor diagnoses all major causes of stream degradation; neither does it provide an adequate guide to effective solutions. In combination with other measures and analyses, however, it can enhance both river protection and restoration.

Management Implications

Development that minimizes the damage to aquatic resources cannot rely on structural BMP's, because there is no evidence that they can mitigate any but the most egregious consequences of urbanization. Instead, control of watershed land-cover changes, including limits to both imperviousness and clearing, must be incorporated (see also Horner and May, 1999). We anticipate needing *all* of the following elements to maintain the possibility of effective protection:

- clustered developments that protect half or more of the natural vegetative cover, preferentially in headwater areas and around streams and wetlands to maintain intact riparian buffers;
- a maximum of 20% total impervious area, and substantially less effective impervious area through the widespread reinfiltration of stormwater (Konrad and Burges, 2001);
- on-site detention, realistically designed to control flow durations (not just peak discharges);
- riparian buffer and wetland protection zones that minimize road and utility crossings as well as overall clearing;
- no construction on steep or unstable slopes; and
- a program of landowner stewardship that recognizes the unique role of adjacent private property owners in maintaining or degrading stream health.

Past experience suggests that each of these factors is important. However, we still lack empirical data on the response of aquatic resources to such "well-designed" developments. Therefore, these recommendations are based only on extrapolations, model results, and judgement; they have yet to be tested. Where development has already occurred, these conditions clearly *cannot* be met and different management objectives are inescapable: many, perhaps all, streams in already-urban areas cannot be truly protected or restored, and a significant degree of probably irreversible stream degradation is unavoidable in these settings.

Our detailed analysis of one feature, *flow regime*, demonstrates the importance of this particular aspect of the aquatic system. Hydrologic alteration is ubiquitous in all urban watersheds, and flow regime is a key determinant of ecological health and biological condition. Stream conditions are not solely determined by flow regime, however, and flow regime is not solely determined by urban development—intrinsic watershed characteristics (watershed geology, soil permeability and depth, topography, channel network, climate) are also relevant. Thus no single watershed indicator can predict flow regime or the consequences of its change on stream conditions, even a metric that provides ecologically useful measures of the variability of stream flow. A new paradigm that systematically ignored water chemistry or the effects of alteration of stream channels, for example, would be no more defensible than previous regulatory mandates that focused *only* on these parameters.

We cannot find any basis to expect that the full range of hydrological and other ecological conditions can be replaced in a now-degraded urban channel (Fig. 5). The key tasks facing watershed managers, and the public that can support or impede their efforts, are therefore (1) to identify those watersheds where existing low urbanization, and associated high-quality stream conditions, warrant the kinds of development conditions that may protect much of the *existing* quality of these systems; and (2) to develop a new set of management goals for those watersheds whose surrounding development precludes significant ecosystem restoration but in which some recovery might be possible. Where urban development is virtually complete, our results (and common sense) suggest that neither widespread riparian-corridor replanting nor extensive hydrologic rehabilitation of the watershed are feasible or could achieve great biological improvements. Stream-enhancement efforts can still be important and worthwhile, for both in-stream biota and the people that live in their watersheds. There is no rational basis to support a common strategy in *all* watersheds, developed and undeveloped alike.

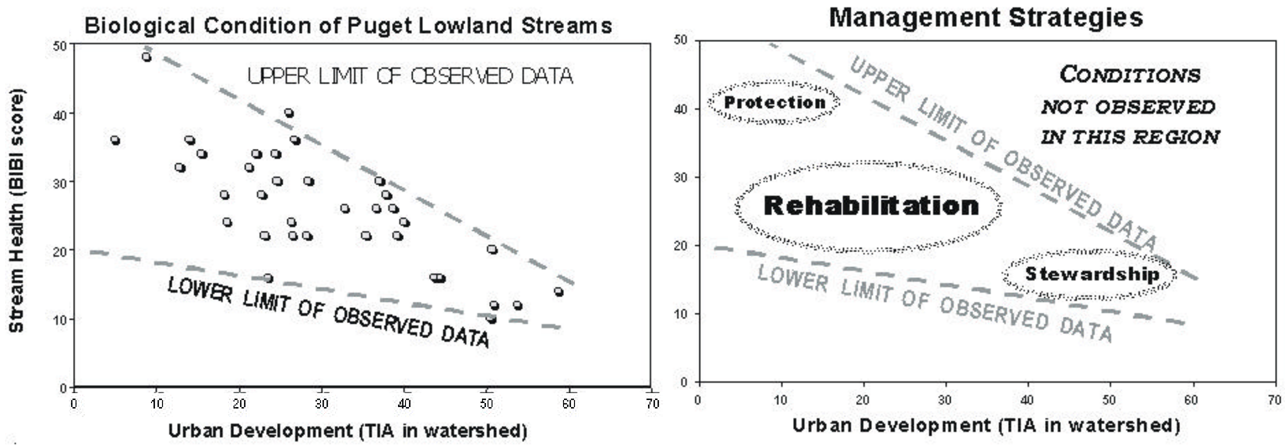

Figure 5: Management strategies as suggested by the distribution of B-IBI data as a function of the % total impervious area (TIA) in the contributing watersheds of our study. Although management goals are commonly articulated for the upper right-hand corner of these graphs (i.e. high-quality streams in highly urbanized watersheds) we find no evidence, and thus little hope, that this does or can occur.

Acknowledgments

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